

Measurements of spin rotation parameter A in pion-proton elastic scattering at 1.62 GeV/c

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Abstract

The ITEP-PNPI collaboration presents the results of the measurements of the spin rotation parameter A in the elastic scattering of positive and negative pions on protons at $P_{\text{beam}} = 1.62$ GeV/c. The setup included a longitudinally-polarized proton target with superconductive magnet, multiwire spark chambers and a carbon polarimeter with thick filter. Results are compared to the predictions of partial wave analyses. The experiment was performed at the ITEP proton synchrotron, Moscow.

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Key words: elastic pion-nucleon scattering, spin rotation parameters, partial wave analysis, baryon spectroscopy, polarized target, carbon polarimeter

1 Introduction

Both the experimental and the theoretical baryon spectroscopy is under steady progress in recent years. The study of photo- and electro-production of non-strange resonances was started by ELSA (Bonn) and CLAS (CEBAF) experiments. As a result of the development of the chiral perturbation theory (CHPT) dynamically generated resonances in the isospin channels $0(\Lambda(1405))$ and $\frac{1}{2}(S_{11}(1535))$ were predicted as a consequence of the existence of quasi-bound $\bar{K}N$ and $K\Sigma$ states [1]. Method of amplitude speed plots was developed [2] for resonance parameter studies. Nevertheless a number of important questions of the baryon spectroscopy is still waiting for their solutions. Among them is the existence of clusters of baryon resonances, low energy of two-phonon excitation (for instance $P_{11}(1440)$), the problem of “missing” resonances in the second resonance region, the role played by the gluonic degrees of freedom at low energies.

Partial wave analysis (PWA) is one of the most powerful instruments in the baryon spectroscopy. But it is still not free from ambiguities caused by the incomplete experimental database. Especially poor is the knowledge on spin rotation parameters A and R in the region of incident particle momenta above 0.75 GeV/c. Predictions of these parameters made by different PWA contradict with each other in a number of kinematic regions. The single measurement in this region fulfilled by the ITEP-PNPI collaboration [3] contradict with predictions of **KH80**¹ [4] and **CMB** [5] and agree with that of **SM90** [6]. The analysis of the data by the method of transverse amplitude zeroes [7] show that the disagreement with **KH80** and **CMB** could be attributed to the discrete ambiguity of Barrelet-type. Absence of the data on spin rotation parameters at the time when these analyses were performed didn’t allow their authors to choose the correct branch of the solution. It was shown that proper amplitude correction results in a good agreement between the predictions of **KH80** and **CMB** and the experimental data, but the parameters of 6 resonances with isospin $\frac{3}{2}$ and masses near 1.9 GeV/c² are significantly changed [8].

This experiment was aimed at several goals: (I) to obtain new experimental data for unambiguous reconstruction of π^+p -elastic amplitudes in the range of $\theta_{cm} = 120\text{--}140^\circ$, where the largest disagreement between predictions of the existing PWA’s is observed; (II) to confirm the choice of the transverse amplitude zero trajectory (solution branch) done in our previous analysis [8]; (III) to test PWA predictions on spin rotation parameters in π^-p -elastic scattering.

¹ Here and later we use the notations of PWA given by their authors

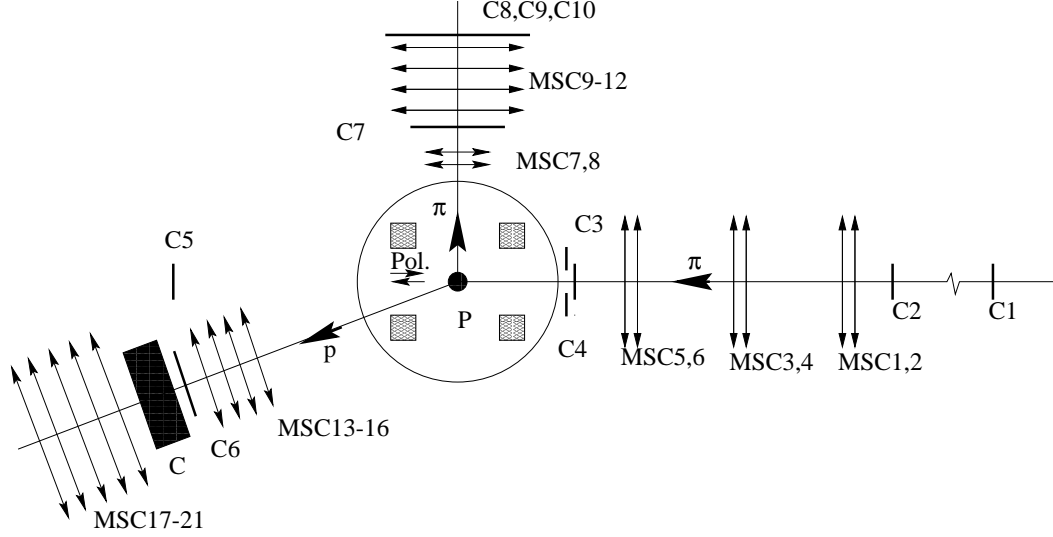


Fig. 1. The experimental layout (not to scale).

2 Experimental conditions

Spin rotation parameter A is measured in the elastic scattering on the longitudinally-polarized proton target as a component of the recoiled proton polarization perpendicular to its momentum and laying in the scattering plane. This component is determined by the secondary scattering of the recoiled protons on the carbon filter.

The apparatus is shown in Fig. 1. Its basic elements are: (i) polarized proton target (P) [9]; (ii) carbon filter (C); (iii) four sets of multiwire magnetostriuctive spark chambers to detect the incident beam (MSC1–MSC6), the scattered pion (MSC7–MSC12) and the recoiled proton before (MSC13–MSC16) and after (MSC17–MSC21) the second scattering and (iv) a number of scintillation counters (C1–C10) to provide the trigger and to identify the positive pions in the beam by the time of flight. A container filled with the target material (propanediol $C_3H_8O_2$ doped by Cr^V complexes) is placed into magnetic field of 2.5 T created by a Helmholtz pair of superconductive coils. The container has a cylindrical form with vertical size and diameter of $30\text{ mm} \times 30\text{ mm}$. Cooling of the target down to 0.5 K is provided by an evaporation-type ^3He cryostat. The polarization is pumped by the dynamic nuclear orientation method up to the absolute value of 70–80 % with the measurement uncertainty 2 %.

The two sets of chambers with the 36.5 g/cm^2 thick carbon filter in between form the polarimeter. The analyzing power of this polarimeter was measured in advance at the polarized proton beam of the ITEP accelerator [10]. The false asymmetry in the polarimeter was also measured with a pion beam and appeared to be 0.0026 ± 0.0014 .

This paper presents the results of two runs at the ITEP accelerator. During the first run 1.4×10^6 triggers with π^+ beam were obtained while the second one gave 6.5×10^5 triggers from π^- beam.

3 Data processing

The processing of the data was performed in several steps:

- Events of the elastic πp scattering on the polarized target were selected by coplanarity and pion-proton angular correlation. $\chi^2 = (\frac{\Delta\phi}{\sigma_\phi})^2 + (\frac{\Delta\theta}{\sigma_\theta})^2$ was calculated for each event, where $\Delta\phi$ and $\Delta\theta$ are deviations from the elastic kinematics in azimuthal and polar angles and σ_ϕ and σ_θ are the RMS of the corresponding distributions obtained from Monte Carlo simulation. χ^2 distributions of the data taken on the polarized target and on a carbon target normalized at $\chi^2 > 35$ are shown in Fig. 2a. The distribution from the carbon target representing

the pure quasielastic background can be approximated with a straight line. The distribution of elastic events with subtracted background follows χ^2 distribution with 2 degrees of freedom (Fig. 2b). The selection criteria $\chi^2 < 5$ corresponds to 6% background and 85% good events after the cut. The normal polarization of the quasielastic background was taken 0.7 of that for the elastic scattering [10]. For every event a 3×3 matrix was calculated, describing recoiled proton spin rotation in the magnetic field of the setup along its trajectory from the vertex of the first scattering to the point of the rescattering on the carbon nucleus.

- Single track events with polar angle of the second scattering $> 3^\circ$ were selected in the polarimeter. From them only those events were taken for which all the azimuthal angles are allowed by the chambers geometry. The average analyzing power for selected events is 0.191. More details on data processing in the polarimeter can be found in [10]. After this selection 16686 events of elastic π^+p scattering and 4708 events of π^-p scattering were left for further processing.

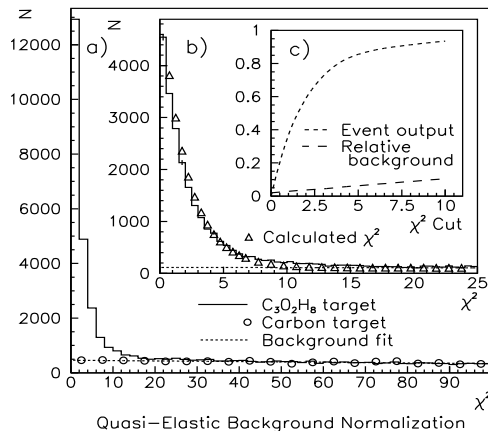


Fig. 2. (a) χ^2 distribution of the events on the polarized target (solid lines) and on the carbon target (open dots). (b) χ^2 distribution of πp elastic events (solid lines) and expected χ^2 distribution (open triangles). (c) Event output and relative background vs χ^2 cut value.

- The method of maximum likelihood was used to get the polarization parameters from the data. The probability density was built only as a function of parameters A and P , while the parameter R was calculated from the equation: $P^2 + A^2 + R^2 = 1$. The result of the fit practically does not depend on the assumption over the sign of R . The likelihood function accounts for: the target polarization, the quasielastic background and its polarization, the analyzing power of the polarimeter and the rotation of the proton spin in the magnetic field between the first and the second scattering.

4 Results

Table 1

Polarization and spin rotation parameters in πp elastic scattering at 1.62 GeV/c.

θ_{cm} (degr.)		P	A	$ R $
range	mean			
π^+p elastic scattering				
118–123.5	121.7	0.24 ± 0.12	0.27 ± 0.18	0.93 ± 0.06
123.5–127	125.2	0.30 ± 0.12	0.36 ± 0.20	0.88 ± 0.09
127–131	128.8	0.40 ± 0.13	-0.32 ± 0.20	0.86 ± 0.10
131–140	133.6	0.29 ± 0.13	-0.40 ± 0.21	0.87 ± 0.11
π^-p elastic scattering				
118–124.8	122.3	-0.11 ± 0.19	0.88 ± 0.28	0.46 ± 0.54
124.8–129.4	127.0	0.03 ± 0.19	0.56 ± 0.28	0.83 ± 0.19
129.4–140	132.8	0.19 ± 0.20	0.51 ± 0.29	0.84 ± 0.18

The results of the experiment are given in the Table 1. Only statistical errors are given. All the systematic errors such as false setup asymmetry, uncertainties in the target polarization, analyzing power, amount and polarization of the background are negligible compared to the statistical errors. The results on the normal polarization P do not contradict within the errors to the results of other works [11–13] and predictions of PWA’s [4–6] (Fig. 3a,b). New results for the parameter A are shown in Fig. 3c,d. Our data for $\pi^+ p$ scattering does not contradict to the predictions given by the analyses **SM90** and **SM99** [6] and is in strong disagreement with the predictions of **KH** [4] and **CMB** [5]. This remains true in a wide momentum range as seen from Fig. 3e,f, where the results of this work are shown together with the data at $P_{\text{beam}} = 1.43$ GeV/c from our previous work [3] for two angles $\theta_{cm} = 127$ and 133° . Thus we confirm the conclusion of Ref. [8] that the difference between several PWA comes from Barrelet ambiguity and from the choice of right trajectory of transverse

amplitude zeroes. In π^-p scattering the parameter A from this experiment does not deviate much from PWA predictions, but looks to be more close to **SM90** and **SM99**.

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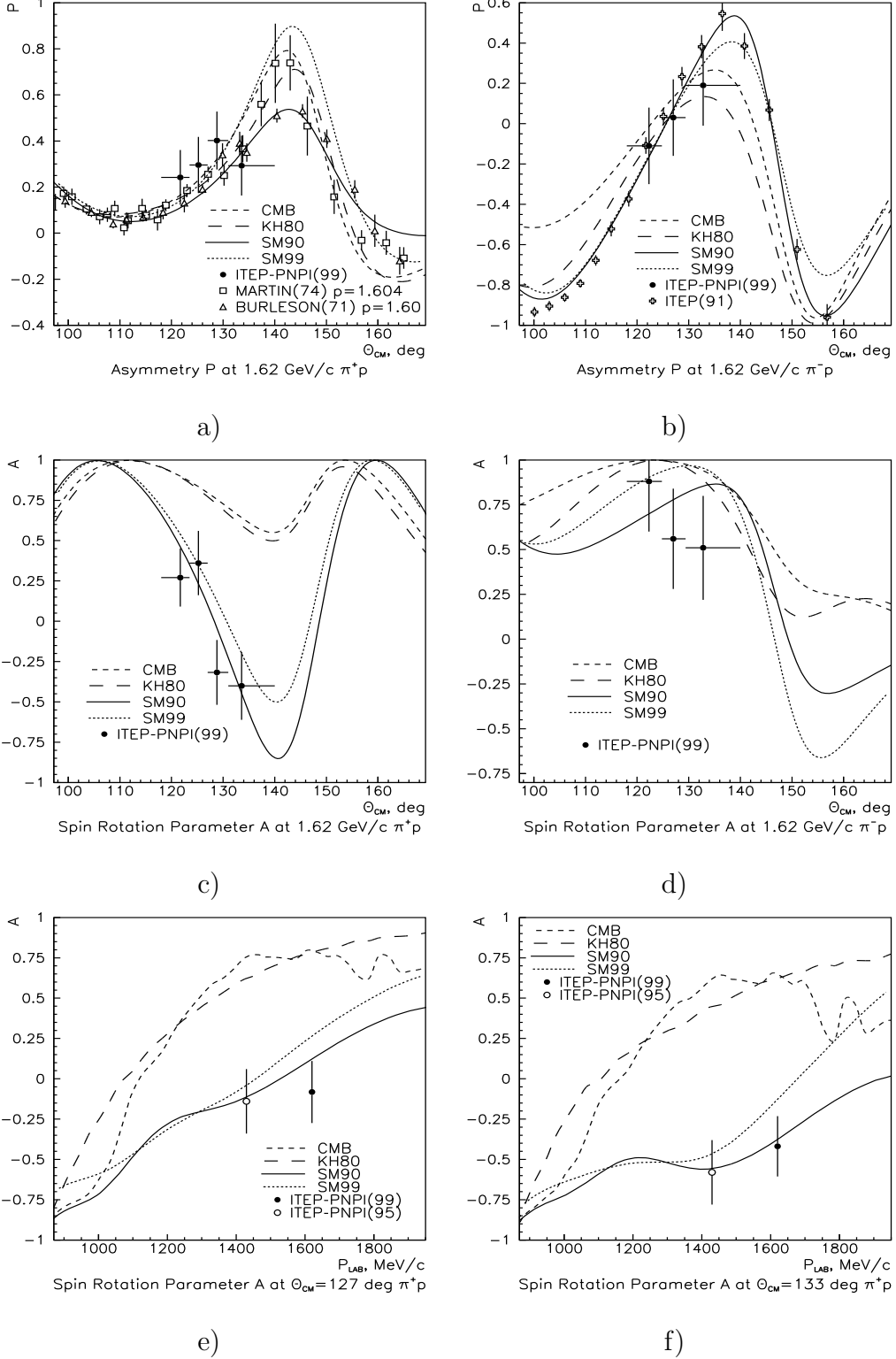


Fig. 3. Results of this work (full dots) compared to the data from [3] (open dots), [13] (open crosses), [11] (open squares), [12] (open triangles) and predictions of selected PWA [4–6]. Polarization P at 1.62 GeV/c in π^+p (a) and π^-p (b) elastic scattering. Spin rotation parameter A at 1.62 GeV/c in π^+p (c) and π^-p (d) elastic scattering. Spin rotation parameter A at $\theta_{cm} = 127^\circ$ (e) and 133° (f) in π^+p elastic scattering.